Spatial time resolution of MCP–PMTs as a time reference with up to sub-4 picosecond precision

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1 – Motivation
• Verification of the MCP–PMTs (R3809U-50 by Hamamatsu) as timing reference in beam tests.
• Measurements done during muon beam tests of PICOSEC Micromegas [1] at CERN SPS/H4.
• The spatial distribution of the time resolution defines the effective usable active area.

2 – Beam Set-up
• Two MCP–PMTs has been operated in parallel.
• Beam telescope has been used in a muon beam.
  – Three triple GEM with strip segmented anode have been used to reconstruct tracks of inclining particle.
  – Coincidence read-out logic of different shaped scintillators are forming a trigger signal.
• Full MCP–PMT signals have been acquired by an oscilloscope (20 GS/s) for an offline analysis.

3 – Efficiency

5 – Light Cone Projection
There are three regions with different behaviour of the Cherenkov light cone projection onto the photocathode:
• Full Signal: The light cone is fully projected onto the photocathode.
• Partial Signal: The cone is partially projected. Decreasing with higher radii from the centre.
• Reflected Signal: The particle is hitting the Cherenkov window further outside and only multiple reflected light reaches the photocathode.

6 – Time Resolution
• The time difference between the two MCP–PMT signals follow a Gaussian distribution.
• Its standard deviation is related to the time resolution of each individual MCP–PMT by:
  \[ \sigma_{\text{tot}} = \sqrt{\sigma_1^2 + \sigma_2^2} \Rightarrow \sigma_{\text{TimeRes}} = \frac{\sigma_{\text{tot}}}{\sqrt{2}} \]
• The time resolution degenerates for particles hitting the detector in the outer regions. These project less light directly on the photocathode and the signal amplitude is smaller.

7 – Conclusions
• The MCP–PMT is useable as a timing reference over the whole area of the photocathode (11 mm ø).
  – The time resolution is under 6 ps and the efficiency is over 95 %.
  – In the outer parts the time resolution reaches the same order of magnitude as the DUTs.
  – The best time resolution can be achieved when the light cone is fully projected.
• A power divider can be used to distribute two oscilloscopes with the same reference signal.
• A reduced sampling frequency has an impact on the fast rising edge shape and the time resolution.

8 – References